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United States
Department of
Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-381

April 1988

Flammability Reduction Comparisons of Four Forest Fire Retardants

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ABSTRACT

Four commercially available forest fire retardants were studied to quantify their capabilities for flammability reduction using standard laboratory conditions and procedures. All the retardants proved to be closely matched in reducing flammability.

KEYWORDS: combustion, fire suppression, chemical retardants, fire-proofing, pyrolysis

The usefulness of forest fire retardants depends on their capabilities to control or reduce combustion of vegetation during wild and prescribed forest and range fires. When applied correctly, the retardant effectiveness depends on the reaction to heat of the basic- fire-inhibiting chemicals in the retardant formulations. The basic- fire-inhibiting chemicals in currently approved and used fire retardants are combinations of ammonium salts of sulfuric and phosphoric acids. The concentration of these chemicals usually determines the effectiveness of the formulation in retarding fire. Several other chemicals may be added to (1) increase the elasticity of the solution, (2) prevent bacterial deterioration, (3) increase the visibility of the solution when applied to the vegetation, and (4) reduce the corrosivity of the retardant solutions to exposed metals.

Some additives and/or impurities (caused by the manufacturing process) can chemically react with the retardant chemical to make compounds that are not effective fire retardants. When new retardants are formulated, their effectiveness can be predicted using their known retardant chemical content, but a decrease or increase in effectiveness caused by a combination of additives/impurities cannot be predicted. Therefore, studies are often conducted to quantify the effects of the additives/impurities and determine if any change in retardant chemical concentration is necessary to overcome these effects. The retardant effectiveness cannot be accurately predicted by analysis of total concentration of active salts, but must be quantified by burning fuels treated with the chemical formulations.

In past years when the price of chemicals was much lower, fire retardant manufacturers formulated and mixed products so that when tested they would easily exceed the USDA requirements (U.S. Department of Agriculture, Forest Service 1986[2]). Consequently, some products were slightly better than others for retarding combustion. When the price of chemicals increased (in the 1970's) and profit margins declined, retardant manufacturers began to formulate products so that only enough retardant chemical was in the formulation to meet the minimum requirements for effectiveness. The result of the more precise formulating has been to bring all approved retardants to about the same level of combustion-retarding effectiveness when tested in the laboratory.

This study was performed to quantify the fire-retarding capabilities of three presently used and one recently submitted forest fire retardants that were formulated containing enough retardant salt to meet the 0.60 superiority factor (S.F.) required in the specifications. The formulations tested are listed in table 1; their retardant salt concentrations are in table 2.[3] Because different retardant salts are not equally effective, weight for weight, table 2 has a list of retardant concentrations expressed as a diammonium phosphate (DAP) equivalency for comparative purposes. P_2O_5 was expressed as DAP by multiplying by 1.86. Monoammonium phosphate (MAP) was first converted to P_2O_5 by dividing by 1.62 then multiplied by 1.86 to determine the DAP equivalent (1.62 and 1.86 are ratios of P_2O_5 derived from the molecular weights of MAP and DAP, respectively). Because ammonium sulfate (AS) had no P_2O_5, another method was necessary to determine the DAP equivalent. From past studies (George and Blakely

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[2]USDA Forest Service, Specification 5100-00304a, Section 3.7. Combustion-Retarding Effectiveness. The mixed retardant shall have a superiority factor between 0.6 and 1.0 . . . .

[3]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—Retardant formulations and their components

Product name	Retardant chemical	Thickener agent	Chemical components[1] added: Corrosion Inhibitor	Spoilage inhibitor	Coloring agent
LC-A[2]	Ammonium polyphosphate	none	yes	no	yes
GTS[3]	Ammonium sulfate/ Diammonium phosphate	industrial gum	yes	yes	yes
D75[4]	Ammonium sulfate/ Monoammonium phosphate	industrial gum	yes	yes	yes
PSF[5]	Diammonium phosphate/ Ammonium sulfate	industrial gum	yes	yes	yes
MAP	Monoammonium phosphate	technical grade chemical only			
DAP	Diammonium phosphate	technical grade chemical only			
AS	Ammonium sulfate	technical grade chemical only			
AS/MAP	Ammonium sulfate/Monoammonium phosphate	combination of technical grade chemicals			

[1]For proprietary reasons, specific chemical names and concentrations are not given.
[2]Firetrol LC-A is a liquid concentrate that is diluted with 5 volumes water added to 1 volume of concentrate.
[3]Firetrol GTS is formulated as a dry powder; it is mixed 1.76 lb per gallon of water.
[4]Phoschek D75 is formulated as a dry powder; it is mixed 1.20 lb per gallon of water.
[5]Firetrol PSF is formulated as a dry powder; it is mixed 1.26 lb per gallon of water.

Table 2—DAP equivalent comparison

Retardant	Ammonium sulfate (AS) content	Diammonium phosphate (DAP) content	Monoammonium phosphate (MAP) content	P_2O_5 content	DAP[1] equivalent
	Percent[2]				
LC-A				7.57	14.08
GTS	13.62	1.21		.65	10.29
D75	8.33		2.77	1.71	8.73
PSF	9.84	2.28		1.23	8.84
MAP			10.38	6.41	11.92
DAP		9.52		5.12	9.52
AS	14.02				9.35
AS/MAP	9.45		3.15	1.94	9.91

[1]DAP equivalence determined on the basis of phosphate concentration for phosphate containing formulations; for sulfates, DAP equivalence determined on the basis of a 1:1.5 ratio of diammonium phosphate to ammonium sulfate equivalency.
[2]Percent chemical in solution by weight.

1972 and unpublished reports on file at the Intermountain Fire Sciences Laboratory) it has been determined that it takes 1.5 times as much AS as DAP to be equivalent in effectiveness on laboratory test fires.

Test fires were also conducted with solutions of the basic fire-retarding chemicals contained within each formulation but without the additives for color, thickness, preservatives, and inhibitors. The fires with basic chemical treatments were used as controls to compare the effects of nonretardant chemical additives and impurities.

METHODS

Fuel beds for the study were constructed, treated, burned, and monitored according to procedures that are explained in USDA Forest Service specification for long-term forest fire retardants (5100-00304a dated February 1986) and detailed by George and Blakely (1972). Fuel beds were constructed with either 6 pounds of ponderosa pine needles or 4 pounds of aspen excelsior. The beds were placed in wire trays 8 feet long by 1½ feet wide and 3 inches deep. The retardant treatments were applied from an overhead sprayer with a fan-shaped spray that uniformly coated the upper layers of the fuel. After treatment, fuels were dried until no retardant water remained (determined by periodic weighing), and the fuels reached approximately 7 percent equilibrium fuel moisture content (FMC) at 90 °F, 20 percent relative humidity. At this time, the beds were placed in a wind tunnel with controlled conditions of 5 mi/h wind, 90 °F air temperature,

Table 3—Superiority factors and retardant coverage

Retardant	Average percent reduction, 1 gal/100 ft²		Average percent reduction, 2 gal/100 ft²		Average DAP equivalent, gal/ft²	Superiority factor
	pp[1]	Exc[1]	pp	Exc		
LC-A	0.409	0.600	0.589	0.829	8.67	0.607
GTS	.403	.669	.611	.769	6.40	.613
D75	.457	.560	.534	.846	5.56	.600
PSF	.389	.683	.532	.769	5.54	.593
MAP	.387	.704	.549	.839	7.11	.620
DAP	.422	.593	.486	.810	5.69	.578
AS	.338	.619	.532	.703	5.88	.548
AS/MAP	.474	.676	.582	.868	6.21	.650

[1]pp is ponderosa pine needles; Exc is aspen excelsior.

and 20 percent relative humidity. Using this method, only the chemical effects were quantified and not the effects of water from the retardant solution or FMC. Each test fuel bed was ignited by a 3-foot-long tray that contained untreated fuel of the same type and fuel loading as the treated bed.

Flame front spread rate and total fuel weight loss while burning were monitored to determine the retardant's ability to suppress combustion. For each fire a superiority factor was calculated by determining the reduction in flame spread rate (R/S) and fuel weight loss rate (R/W) caused by treatments. Percent reduction in burning rates was calculated by comparing R/S and R/W for untreated fuel with R/S and R/W for treated beds. The test fires (two replicates of each for AS/MAP and three for all others) were conducted with two different fuels (pine needles and aspen excelsior) and two different treatment levels (1 and 2 gallons per 100 square feet (gal/100 ft²). The superiority factor was calculated by combining percent reduction from at least 12 fires for each retardant (eight for AS/MAP). A standard error of the mean was applied to the average percentage reduction for these fires at each treatment level with each fuel. Then the average reduction for each group of fires was calculated to determine the S.F. shown by all fires for a retardant (table 3).

RESULTS AND DISCUSSION

Combustion rates were measured for 130 fires in treated and untreated fuel beds. Table 3 shows the reduction in combustion rates and superiority factors for the chemicals tested. An average DAP equivalent in grams/ft² was calculated, and the actual chemical coverage levels are listed in table 2 for comparisons. Treatment levels and subsequent burning rates for different fuels and treatments are presented in the appendix, "Summary of Treatments and Superiority Factors." Also shown are the water-to-retardant mix ratios and the retardant chemical concentrations in each formulation.

The three currently approved fire retardants, LC-A, GTS, and D75 have SF's of 0.607, 0.613, and 0.600, respectively. PSF, a new retardant that is presently being studied, has a superiority factor of 0.593. LC-A effectiveness can be compared to the P_2O_5 content of technical grade MAP or DAP. It appears that some effectiveness may be lost because of the form of P_2O_5 and additives in the LC-A, as shown in earlier studies of similar polyphosphate based retardants (George and others 1977). The average coverage levels for LC-A and MAP (appendix) are about equal, but MAP (6.41 percent P_2O_5) has a slightly higher S.F. apparently because of the reasons stated previously.

GTS effectiveness can be compared to that of technical grade AS. Both retardants have equal coverage levels and about the same (14 percent) AS content. But the addition of 1.21 percent (0.65 percent P_2O_5) DAP to GTS appears to significantly improve combustion reduction and also compensate for any reduction in effectiveness that might be caused by additives in GTS.

The formulated D75 has a 3 to 1 ratio of AS and MAP, the same ratio as the technical grade AS/MAP combination. The superiority factor for D75 is lower than that for AS/MAP because of slightly lower AS and MAP concentrations, and more additives. PSF, with more AS and less P_2O_5 than either D75 or AS/MAP, has a lower superiority factor than either of them.

One unexpected result was the relatively low percentage of reduction caused by DAP and AS when used alone as compared to the higher percentage of reduction caused by combinations of DAP and AS when the DAP equivalent levels (table 3) are about equal. GTS and AS/MAP have significantly higher coverage and show a corresponding higher superiority factor. But D75 and PSF (with 3 to 1 ratios of AS to MAP) have DAP equivalent coverage almost identical to DAP and AS alone and yet have significantly higher superiority factors. More study is necessary to determine if and why synergism occurs when DAP and AS are combined.

MANAGEMENT APPLICATIONS

When a value analysis system (USDA Forest Service 1984) is used to select a fire retardant at a retardant base, one of the criteria is retardant effectiveness. Effectiveness is weighted as 50 percent or more of the total

evaluation. Effectiveness is composed of seven elements: line length, wind drift, penetration, coverage, recovery, flammability reduction, and visibility. All seven of these elements are weighted separately for use in the rating process and may be weighted differently for each different retardant.

Results of this study illustrate how closely all the currently approved retardants for aerial delivery match in flammability reduction ability. No one currently approved retardant is significantly superior to any other when tested in the laboratory under the same conditions and procedures. Therefore, all currently approved retardant formulations should be rated equally for flammability reduction, and the other effectiveness elements can be weighted discriminately to decide the final effectiveness score.

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APPENDIX: SUMMARY OF TREATMENTS AND SUPERIORITY FACTORS

Retardant chemical: LC-A

Specific gravity: 1.082 Mix Ratio: 5 water/1 concentrate volume

Chemical in solution (%): P_2O_5 7.57;

Date	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
1981	0.99	485	6.10	1.29	0.400	176	0.438	0.419			
	0.99	485	6.10	1.28	.405	192	.387	.396	0.397	0.022	0.012
	0.97	479	6.03	1.25	.419	209	.332	.376			
	1.91	936	11.78	0.75	.651	170	.457	.554			
	2.01	987	12.42	0.77	.642	136	.565	.604	.573	.027	.016
	1.91	937	11.79	0.76	.647	164	.476	.562			
			Untreated	2.15		313					
					Aspen excelsior						
1981	1.02	502	6.32	2.18	.497	188	.605	.551			
	1.02	500	6.29	1.60	.630	245	.485	.558	.577	.039	.023
	1.02	503	6.33	1.48	.658	197	.586	.622			
	2.16	1,060	13.34	0.66	.848	84	.824	.836			
	2.01	989	12.44	0.53	.878	114	.761	.820	.817	.021	.012
	2.03	995	12.52	0.67	.845	122	.744	.795			
			Untreated	4.33		476					
	1.50	738	9.29					Averages =	0.591		0.016
									+0.016		
								Superiority factor	0.607		

APPENDIX (Con.)

Retardant Chemical: GTS

Specific Gravity: 1.099 Mix Ratio: 1.76#/gallon water

Chemical in Solution (%): Ammonium sulfate 13.62; Diammonium phosphate 1.21

Date 1985	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
Apr 8	1.02	510	6.30	1.20	0.381	194	0.273	0.327			
	0.98	488	6.03	1.28	.340	196	.266	.303	0.359	0.077	0.044
Apr 11	0.90	451	5.57	0.84	.497	168	.394	.446			
Apr 8	2.09	1,044	12.90	0.50	.742	147	.449	.596			
Apr 11	1.97	985	12.17	0.53	.683	126	.545	.614	.595	.028	.016
Apr 11	1.97	984	12.16	0.59	.647	138	.502	.575			
Apr 8			Untreated	1.94		267					
Apr 11			Untreated	1.67		277					
					Aspen excelsior						
Apr 9	0.99	494	6.11	1.33	.706	219	.437	.572			
	1.01	506	6.25	1.14	.748	159	.591	.670			
Apr 10	1.00	500	6.18	0.76	.791	172	.580	.686	.642	.062	.027
May 5	0.98	487	6.02	1.36	.700	254	.455	.578			
	0.98	490	6.06	1.27	.720	146	.687	.704			
Apr 9	2.05	1,023	12.64	0.83	.817	184	.527	.672			
Apr 10	2.02	1,008	12.45	0.58	.841	146	.643	.742	.735	.059	.034
Apr 10	1.95	972	12.01	0.50	.863	116	.717	.790			
Apr 9			Untreated	4.53		389					
Apr 10			Untreated	3.64		410					
May 5			Untreated	4.53		466					
	1.50	747	9.23					Average =	0.583		0.030
									±0.030		
								Superiority factor	0.613		

APPENDIX (Con.)

Retardant Chemical: D75

Specific Gravity: 1.071 Mix Ratio: 1.20#/gallon water

Chemical in Solution (%): Ammonium sulfate 8.33; Monoammonium phosphate 2.77

Date 1981	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
3/2	0.94	458	4.20	1.01	0.502	188	0.455	0.479			
3/3	1.04	507	4.65	1.19	.414	199	.423	.419	0.434	.039	.023
3/4	1.05	508	4.66	1.14	.438	217	.371	.405			
3/3	2.05	995	9.12	0.85	.571	195	.435	.508			
3/4	2.10	1,020	9.35	0.87	.581	176	.490	.531	.525	.015	.009
3/4	2.08	1,010	9.26	0.85	.562	175	.493	.537			
			Untreated	2.03		345					
					Aspen excelsior						
3/3	1.15	558	5.12	2.50	.413	218	.588	.501			
3/3	1.07	520	4.77	1.91	.552	190	.641	.597	.519	.071	.041
3/4	1.13	551	5.05	1.97	.538	328	.380	.459			
3/3	2.07	1,006	9.22	0.54	.873	99	.833	.853			
3/3	2.07	1,007	9.23	0.56	.869	109	.794	.832	.840	.011	.006
3/4	2.14	1,039	9.52	0.54	.873	107	.798	.836			
			Untreated	4.26		529					
	1.57	765	7.01					Averages =	0.580		0.020
									+0.020		
								Superiority factor	0.600		

APPENDIX (Con.)

Retardant Chemical: PSF

Specific Gravity: 1.076 Mix Ratio: 1.26#/gallon water

Chemical in Solution (%): Ammonium sulfate 9.84 ; Monoammonium phosphate 2.28

Date 1986	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
12/15	0.90	441	4.45	1.63	0.432	231	0.364	0.398			
12/16	1.04	506	5.11	1.82	.257	235	.294	.276	0.351	0.065	0.038
12/17	1.03	505	5.10	1.35	.386	205	.369	.378			
12/15	1.98	967	9.77	1.24	.568	167	.540	.554			
12/16	2.01	982	9.92	1.27	.482	190	.429	.456	.504	.049	.028
12/17	2.11	1,032	10.42	1.13	.486	157	.517	.502			
12/15			Untreated	2.87		363					
12/16			Untreated	2.45		333					
12/17			Untreated	2.20		325					
					Aspen excelsior						
12/15	0.94	459	4.64	2.22	.583	198	.574	.579			
12/16	1.05	511	5.16	1.75	.679	174	.613	.646	.645	.066	.038
12/17	1.03	504	5.09	1.40	.703	128	.716	.710			
12/15	2.14	1,045	10.75	0.85	.841	163	.649	.745			
12/16	2.13	1,044	10.54	0.92	.832	194	.569	.701	.744	.043	.025
12/17	2.12	1,037	10.47	0.65	.862	130	.711	.787			
12/15			Untreated	5.33		465					
12/16			Untreated	5.46		450					
12/17			Untreated	4.71		450					
	1.54	753	7.61				Averages =		0.561		0.032
									+0.032		
							Superiority factor		0.593		

APPENDIX (Con.)

Retardant Chemical: MAP

Specific Gravity: 1.054 Mix Ratio: _____

Chemical in Solution (%): Monoammonium phosphate 10.38; _____

Date 1985	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
4/19	0.91	434	3.75	1.46	0.324	176	0.328	0.326			
4/19	0.98	470	4.07	1.24	.426	159	.393	.410	0.362	0.043	0.025
4/19	1.02	488	4.22	1.46	.324	164	.374	.349			
4/22	2.07	990	8.56	0.96	.556	146	.579	.568			
4/22	1.97	941	8.14	1.20	.417	149	.571	.494	.527	.038	.022
4/22	1.95	930	8.04	1.05	.514	165	.524	.519			
4/19			Untreated	1.78		262					
4/22			Untreated	2.16		347					
					Aspen excelsior						
4/17	0.96	459	3.97	1.40	.685	173	.601	.643			
4/18	0.95	454	3.93	1.24	.726	203	.556	.641	.673	.054	.031
4/18	0.98	470	4.07	0.87	.808	154	.663	.736			
4/17	2.22	1,059	9.16	0.50	.887	126	.710	.799			
4/17	2.00	956	8.27	0.53	.881	107	.753	.817	.823	.027	.016
4/18	1.96	938	8.40	0.44	.903	73	.800	.852			
4/17			Untreated	4.44		434					
4/18			Untreated	4.53		457					
	1.50	716	6.19					Averages =	0.596		0.024
									±0.024		
								Superiority factor	0.620		

APPENDIX (Con.)

Retardant Chemical: DAP

Specific Gravity: 1.061 Mix Ratio: _____

Chemical in Solution (%): Diammonium phosphate 9.52; _____

Date 1985	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
5/13	0.88	424	3.36	1.40	0.310	193	0.350	0.330			
	0.95	458	3.63	1.55	.236	204	.313	.275	0.361	0.105	0.061
5/14	1.10	529	4.20	1.10	.427	146	.531	.479			
5/13	1.93	930	7.37	1.13	.443	175	.411	.427			
5/14	1.98	952	7.55	1.20	.375	152	.511	.443	.460	.045	.026
	2.01	967	7.67	1.01	.474	141	.547	.511			
5/13			Untreated	2.03		297					
5/14			Untreated	1.92		311					
					Aspen excelsior						
5/9	1.01	485	3.85	1.47	.682	207	.581	.632			
5/10	0.99	477	3.78	2.76	.369	214	.572	.471	.546	.081	.047
	0.92	442	3.51	1.79	.500	216	.568	.534			
5/9	2.06	991	7.86	0.54	.883	109	.779	.831			
	1.98	953	7.56	0.81	.825	159	.678	.752	.787	.040	.023
5/10	2.07	996	7.90	0.66	.816	129	.742	.779			
5/9			Untreated	4.62		494					
5/10			Untreated	3.58		500					
	1.49	717	5.69					Averages =	0.539		0.039
									+0.039		
								Superiority factor	0.578		

APPENDIX (Con.)

Retardant Chemical: AS

Specific Gravity: 1.084 Mix Ratio:

Chemical in Solution (%): Ammonium sulfate 14.02;

Date 1985	Treatment applied Level	Wet	Dry	Rate of flame spread	Reduction	Rate of weight loss	Reduction	Superiority factor Each fire	Each group Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
3/29	1.03	505	5.90	1.17	0.378	194	0.324	0.351			
	1.07	526	6.14	1.37	.344	225	.297	.321	0.320	0.032	0.018
	1.02	502	5.87	1.50	.282	226	.294	.288			
3/28	2.03	1,001	11.70	0.98	.479	156	.456	.468			
	2.05	1,011	11.81	1.03	.452	166	.421	.437	.492	.070	.040
	2.12	1,041	12.16	0.86	.589	144	.550	.570			
3/28			Untreated	1.88		287					
3/29			Untreated	2.09		320					
					Aspen excelsior						
3/26	1.01	495	5.78	2.22	.583	232	.470	.527			
3/27	0.95	465	5.43	1.42	.704	177	.558	.631	.588	.054	.031
	0.99	488	5.70	1.67	.652	176	.560	.606			
3/26	2.11	1,037	12.12	0.81	.848	207	.527	.688			
	2.09	1,030	12.03	0.88	.835	180	.589	.712	.693	.017	.010
3/27	1.92	947	11.06	0.79	.835	191	.523	.679			
3/26			Untreated	5.33		438					
3/27			Untreated	4.80		400					
	1.53	754	8.81					Averages =	0.523		0.025
									±0.025		
								Superiority factor	0.548		

APPENDIX (Con.)

Retardant Chemical: AS/MAP

Specific Gravity: 1.082 Mix Ratio:

Chemical in Solution (%): Ammonium sulfate 9.45 ; Monoammonium phosphate 3.15

Date	Treatment applied			Rate of		Rate of		Superiority factor			
								Each	Each group		
1981	Level	Wet	Dry	flame spread	Reduction	weight loss	Reduction	fire	Ave.	Std. dev.	Std. error
	Gal/ 100 ft²	*g/bed*	*g/ft²*	*Ft/min*	*Percent*	*g/min*	*Percent*				
					Ponderosa pine needles						
Feb.	1.00	493	5.18	1.30	0.360	182	0.472	0.416			
	0.97	477	5.01	1.10	.458	176	.490	.474	0.445	0.041	0.029
	2.19	1,078	11.32	.72	.645	166	.519	.582			
	1.92	944	9.91	.80	.606	154	.554	.580	.581	.001	.001
			Untreated	2.03		345					
					Aspen excelsior						
	1.00	490	5.15	1.16	.728	199	.624	.676			
	1.06	520	5.46	1.51	.646	185	.650	.648	.662	.020	.014
	2.03	998	10.48	.44	.897	87	.836	.867			
	2.05	1,005	10.55	.51	.880	114	.728	.804	.836	.045	.032
			Untreated	4.26		529					
	1.53	751	7.88					Average =	0.631		0.019
									±0.019		
								Superiority factor	0.650		

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